VARIOUS PROPERTIES OF SAND AS AFFECTING ITS USE IN CONCRETE AND MORTAR

BY

E. E. ALTMAN

ARMOUR INSTITUTE OF TECHNOLOGY

1 9 1 6

AN INVESTIGATION OF THE VARIOUS PROPERTIES OF SAND AS AFFECTING ITS USE IN CONCRETE AND MORTAR

A THESIS

PRESENTED BY

EUGENE E. ALTMAN.

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN CIVIL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

CIVIL ENGINEERING

APPROVED:

Alfred E. Phillips
PROFESSOR OF CIVIL ENGINEERING

L. M. Raymond
DEAN OF ENGINEERING STUDIES

DATE May 6th 1916

DEAN OF CULTURAL STUDIES

Preface

At the present time engineers are making a study of sand for the improvement of concrete, and this paper has been prepared with the object of improving sand for its use in concrete and mortar. The paper contains the laboratory methods of making the tests and a discussion of each.

The author wishes to express his appreciation and thanks to Prof. Stanley Dean, of the Civil Engineering Department, and to Mr. Phillip C. Huntly of the Mechanical Engineering Department, for their assistance and suggestions in developing this paper.

E.E.A.

Table of Contents.

Table of Contents

Continued

List of Illustrations and Curves.

List of Tables

Introduction.

The purpose of this work is to determine both the suitability and properties of sand for its use in masonry construction. After the properties of the sands have been determined, some of the sand samples are graded, providing that their granulometric analysis shows that grading will be profitable. An investigation is then made on some of the sands in order to improve the strength of their mortars, by altering the percentage of aggregate.

At the present time, there is no standard method of testing sand in common acceptance, but the following outline is the general procedure that has been recommended for practical sand testing, and has been used throughout this work.

(I) Physical Tests of Aggregate.

1. Weight per cubic foot.
2. Percentage of moisture.
3. Percentage of voids.
4. Specific gravity.
5. Percentage of silt.
6. Granulometric analysis.
7. Description of sand samples.

(II) Tensile and Compressive Strength of Mortars.

1. Ungraded sand.
2. Graded sand.
3. Comparison of the above mortars with a mortar of Ottawa Standard Sand.

In spite of the oft-repeated utterances of competent authorities made year after year, as to the importance of testing sand, little actual headway has been made towards convincing the average concrete constructor that such tests are both beneficial and necessary. There has been a steady increasing appreciation of the value of sand testing. This appreciation finds expression in the fact that some of the largest engineering organizations, municipal, State and Federal undertakings employ large quantities of concrete and mortar, and make a regular practice of testing sand in their work. In addition, some of the States have taken up the subject through their geologists, and have made a qualitative and quantitative survey of the sand deposits within their borders. In spit of all this educative effort, the men who use the most of the cement still believe that "sand is sand", and that there is no need of testing it.

The object of most of the tests upon sand at the present time is either to determine which of two or more sands is the better or whether or not a particular sand can be used, regardless of getting

the best results. Frequently, a proper application of the data obtained through a thorough series of tests of the materials available at a particular job would lead to a marked improvement in the quality of the sand used, either by adjusting the proportions of fine or course aggregate, washing the sand, or mixing two or more sands to make a combination better than any one of the constituents.

The increased use of portland cement mortar and concrete in masonry construction has led to the investigation of sand deposits and the properties of sand. The great quantities of sands which are obtained from different deposits will differ in their character, due to the various geological conditions. Hence the various sand deposits in any one locality must be investigated so that the sand for a "job" will be of the best quality. It is probable that no one factor influence the quality of concrete is more important than the sand used, both in character and quantity The sand is usually one-third the total volume of concrete, but this one-third is made up of millions of small particles or grains, each of which must be

coated with cement and tied to its neighbor.

Hitherto there has been no definite specification for sand. The reason for no definite specifications is found in the fact there is so much variations in sands. The layers in the same pit vary among themselves, and the sand in one district being quite different from that in another. Since sand is an important element in masonry construction, it would be expected that the sand should be carefully selected and tested before it is put in a structure, in order that the mortar and concrete produced will be of the highest quality. Strict specifications and tests are made for cement, brick and other materials of construction, but all the specifications say about sand that it shall be "clean and sharp." As a result of poor sand, the mortar and concrete produced will be deficient in strength and durability.

In summarizing the reason for sand testing, we may say the primary function of sand tests is to render good concrete. In order to have good concrete there must be three requisites for sand.

First:-

The cement must bind the sand particles together, each grain must be clean.

Second:-

Each sand particle must be able to bear a portion of the total load imposed on the concrete.

Third:-

The grains should be graded in size so that there will be no spaces between the grains.

Preparation of Samples.

In almost every case a typical sample of any one deposit was collected. The sample was collected from different parts of the deposit, and shipped unwashed and ungraded.

The samples were shipped to the laboratory in cloth bags, containing 1 1/2 cu.ft. As soon as a sample was received, it was given a "sample number" for identification. The sample was screened to pass a one-quarter inch sieve, and the weight per cubic foot and the percent of moisture obtained. The bags were stored on shelves several feet off the laboratory floor, care being taken that no foreign material or other sands were mixed with the sample.

About one-half of the sample was thoroughly washed, and dried. Part of the washed sand was graded as described on page (53). As each sample had for its identification number a letter, and to distinguish the washed, unwashed and graded sands from each other, this letter preceded a number. Unwashed, washed and graded sands are represented by

the number 1, 2, 3 respectively. For example, C-1, C-2, C-3 represent sample C as unwashed, washed and graded sand respectively. These notations were marked on each test piece.

Each sample was tested for weight per cubic foot, percentage of moisture, percentage of silt, specific gravity, percentage of voids, gradation of size of grains (granulometric analysis); and compression and tensile tests were made on the mortar of each.

Cement Tests.

All the cement used in this work is subjected to the following physical tests:

(1) Specific gravity.

(2) Fineness.

(3) Time of initial and final set.

(4) Tensile and compressive strength of neat cement mortar, and a mortar of one part of cement to three parts of Ottawa Standard Sand.

(5) Percentage of water for normal consistency.

(6) Soundness.

The cement used throughout this work was Chicago "AA" portland cement. This cement was purchased on the open market. The above tests were made according to the methods adopted by The American Society of Testing Materials, August 16, 1909.

The specific gravity of the cementwas determined in a LeChatelier apparatus. The fineness was made by sifting the cement through the # 100 and # 200 sieves by hand. The apparatus for the test for soundness was a special copper boiler. The test consisted in maintaining the pats in an atmosphere of steam over boiling water for five

hours. The tests for normal consistency and the time of initial and final set were determined by means of the Vicat apparatus. The tensile and compressive strengths were determined in machines described on page (25).

Tensile strength in pounds per square inch.

Neat Cement.	
24 hours in moist air	241
7 days (1 day in moist air,6 day in water	575
28 days (1 day in moist air,27 days in water	695
90 days	546
One part cement, Three parts Standard Ottawa Sand	
7 days (1 day in moist air, 6 days in water	200
28 days (1 day in moist air,27 days in water	282
90 days	382

Compressive strength in pounds per square inch.

Neat Cement	
24 hours in moist air	1035
7 days (1 day in moist air,6 days in water	4375
28 days (1 day in moist air,27 days in water	6600
90 days	8000
One part cement, Three parts Ottawa Standard Sand.	
7 days (1 day in moist air, 6 days in water	1000
28 days (1 day in moist air,27 days in water	1605
90 days	2180

Percent of water required to form a paste of normal consistency = 24.2%

Fineness

Percent retained on #100 sieve = 3.6%
Percent retained on #200 sieve = 23.8%

Time of Set

Initial set	1 hour 20 minutes
Final set	5 hours 10 minutes

Soundness

The pats showed no sign of distorsion, checking or cracking in the normal or accelerated test.

Percent of Moisture

The amount of moisture in each sample was determined as soon as possible after the arrival of the sample. This was done to prevent any of the moisture from being driven off, as the laboratory was extremely warm. The sand was thoroughly mixed, and 1000 grams of the sample was heated over a rose burner for 20 minutes. The sample was placed in a plate about 10 inches above the flame.

After the sample had been heated, it was weighed again, and this weight subtracted from 1000 grams gave the amount of moisture in 1000 grams. To find the percentage of moisture, divide the amount of moisture in the sample by 1000, and multiply by 100%.

Twenty minutes was found to be long enough to drive off all the moisture. After several trials of heating the sand and weighing it, and

then heating again and re-weighing, there was no more loss in weight due to moisture being driven off at the end of 20 minutes. On page (35) is shown the mean of 3 determinations. The value of determining the amount of moisture present is used in making corrections in the calculations of the weight per cubic foot.

Weight per Cubic Foot

The method employed to find the weight per cubic foot is as follows: The sample was allowed to fall freely from a height of 3 feet into a vessel containing 0.2905 cu. ft. When the vessel was about one-quarter full, it was jarred by allowing it to fall several times on the floor from a height of 3 inches. The reason for doing this is to prevent the sand from compacting. As the vessel was being filled, this was repeated several times. When the vessel was filled, the surface of the sand was struck off even with the top of the vessel, and weighed. The weight of the sand in the vessel was obtained by taking the difference between the weight of the empty vessel, and the weight of the full vessel. This gives the weight of 0.2905 cu. ft. of sand, and in order to find the weight per cubic foot, divide the above weight of sand by 0.2905. The results given on page (35) are the mean of five determinations.

The contents of the vessel used was found by filling it with water and then weighing it. The weight of the empty vessel was then subtracted from the weight of the filled vessel, and this gave the weight of the water. Dividing the weight of the water by 62.4, gave the cubic contents of the vessel.

The results of this test are made use of in determining the percent of voids. Multiplying the specific gravity of the sand by the weight of a cubic foot of water, gives the weight of a cubic foot of the solid material. Divide the weight of the loose material by the weight of the solid, which gives the proportion of voids.

The determination of weight per cubic foot test is subject to the same shortcomings as the void test as explained before is: the want of a constituent and standardized method of making, and the lack of a useful purpose to which the results may safely be put.

Making up Mortar Briquettes and Cylinders

The laboratory equipment consisted of trowels, scales, graduates, pans, glass plates, moist air closet, and everything to carry out the work as outlined. The cement was stored in a water tight and almost air tight receptacle.

The mixing plates were of heavy glass 20" by 30". The molds used for the tensile tests were standard briquettes as recommended by the "American Society for Testing Materials", as shown on page (20). The molds are made of brass and consist of two like parts which will match up. The briquette can be removed from the mold by loosening a clamp which holds the sides of the molds together. The molds used in this work were either gang molds or single molds.

The molds used for the compression tests were cylinders 2 inches in diameter and 4 inches high, and made of #16 rolled galvanized iron. These

molds were rolled to a diameter slightly larger than 2 inches, and the sprung to the proper diameter by circumferential clamps which could be tightened.

The moist closet consisted of a receptacle about 25" X 32" X 42", and a 4" water pan in the bottom. The interior surface was covered with galvanized iron. The interior of the closet was provided with glass shelves on which to place the test pieces, the shelves being so arranged that they could be withdrawn readily.

The pans for storing the tests pieces, after being 24 hours in the moist closet, were galvanized iron pans 20" X 30" X 5" deep.

Mixing:

The mortar throughout all this work was made of one part of portland cement to three parts of sand. The proportions were taken according to their weight measurement in grams.

This proportion in the mortar was used because it was thought that if a lean mixture were used, the strength of the test pieces would be decreased too much. If a richer mixture were used, the properties of cement might offset the poor qualities of some of the sand samples.

The sand and cement were weighed and placed on cleaned glass plates. It was found after several trials that six batches of mortar containing 1333.3 grams of sand and cement were sufficient to make 12 briquettes and 12 cylinders. In this mixture there were 1000 grams of sand and 333.3 grams of cement.

The sand and cement were spread out evenly on the glass plate, and dry mixed by turning the materials with a trowel. The sand and cement were turned until the mixture was uniform in color, and then a crater was formed in the center of the pile.

After each batch had been mixed in this way, water was poured slowly into the crater of one of the batches. The material from the outer edge was

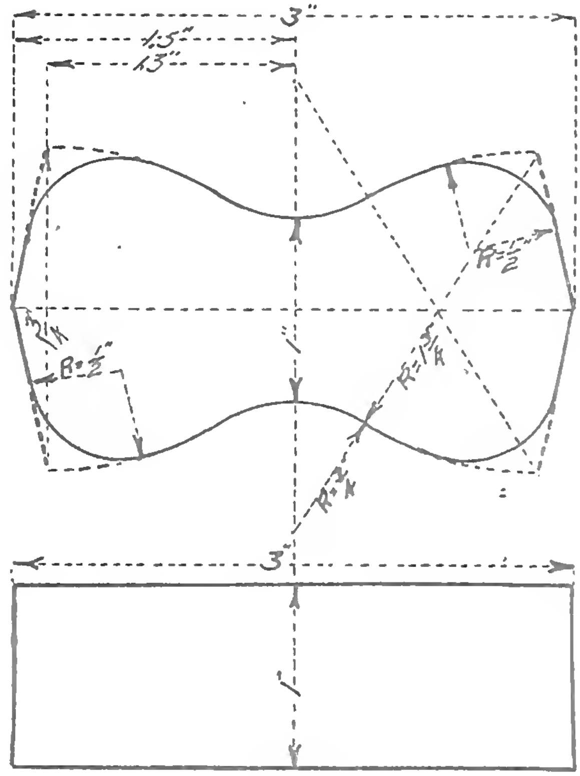
turned onto the crater by the aid of the trowel. When all the water had been absorbed, the materials were vigorously mixed for two minutes. Water was not added to a second batch until the mortar from the first batch had been placed in the molds.

The amount of water to be added had been previously determined from a table given in the "Standard Specifications for Portland Cement." It was found that the normal consistency of the cement used required 24.5% of water, and from this table 9.6% of water is required for a one to three mortar. The amount of water to be added is a percentage of the combined weight of the sand and cement. In some of the samples slightly more water was added ranging from 0.1% to 0.3%, depending upon the fineness of the sand. Fine sand requires more water than a sand containing a large amount of coarse particles. On page (25 to 30) is shown the percentage of water added to each mortar.

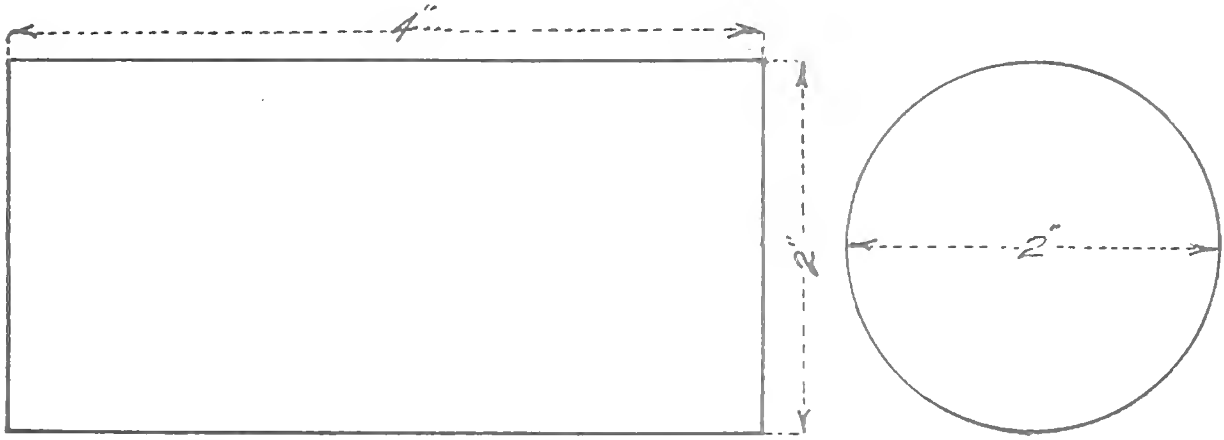
After each batch had been mixed, the mortar was put into molds. The inside surfaces of the molds

were cleaned and oiled before any mortar was put into the molds. The molds were set on glass plates, while being filled with mortar. The mortar was placed into the briquette molds by hand, and then pressed in firmly with the fingers. The mortar was heaped on the mold and then smoothed off with a trowel. In filling the cylindrical molds, about one inch of mortar was placed in the mold and then rammed gently. Increments of one inch of mortar were placed in the molds until it was filled. The top surface was the one smoothed off by aid of the trowel. The molds were then put on a glass plate, which was covered with oiled paper, and then placed in the moist closet for 24 hours.

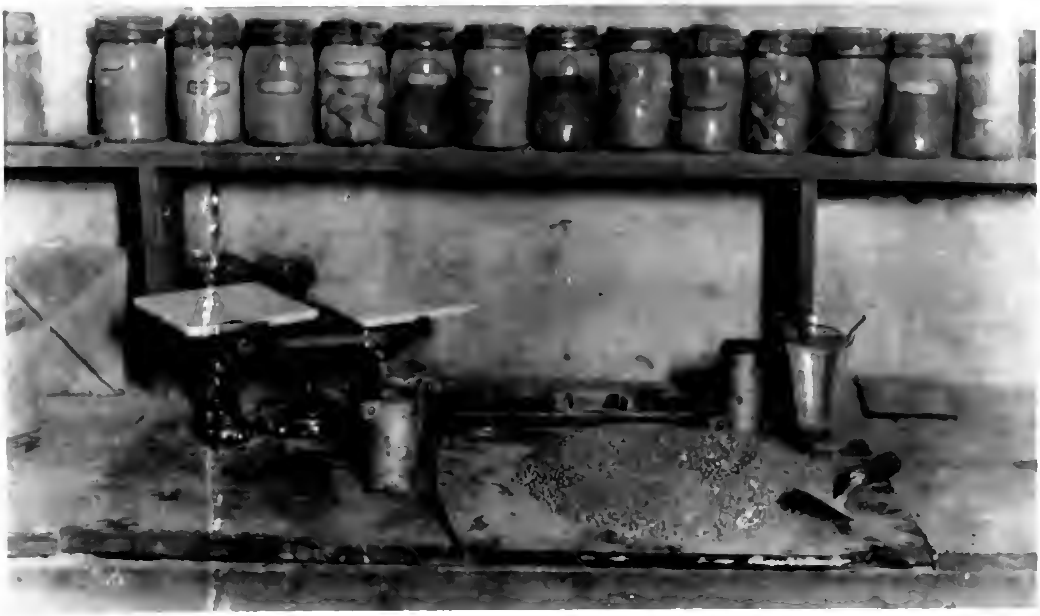
All test pieces were kept in a moist closet for the first 24 hours after molding. The molds were then removed from the test pieces, and the test pieces were immersed in water in the storage pans, and kept until tested.



DETAILS FOR BRIQUETTE



DETAILS FOR CYLINDER



Method of Mixing Mortar

Strength Tests

The test pieces were kept immersed in water in the storing pans for a period of 7, 28, 90 days after mixing. As soon as the pieces were taken out of water, they were taken to the testing laboratory and tested for their strength in tension and compression.

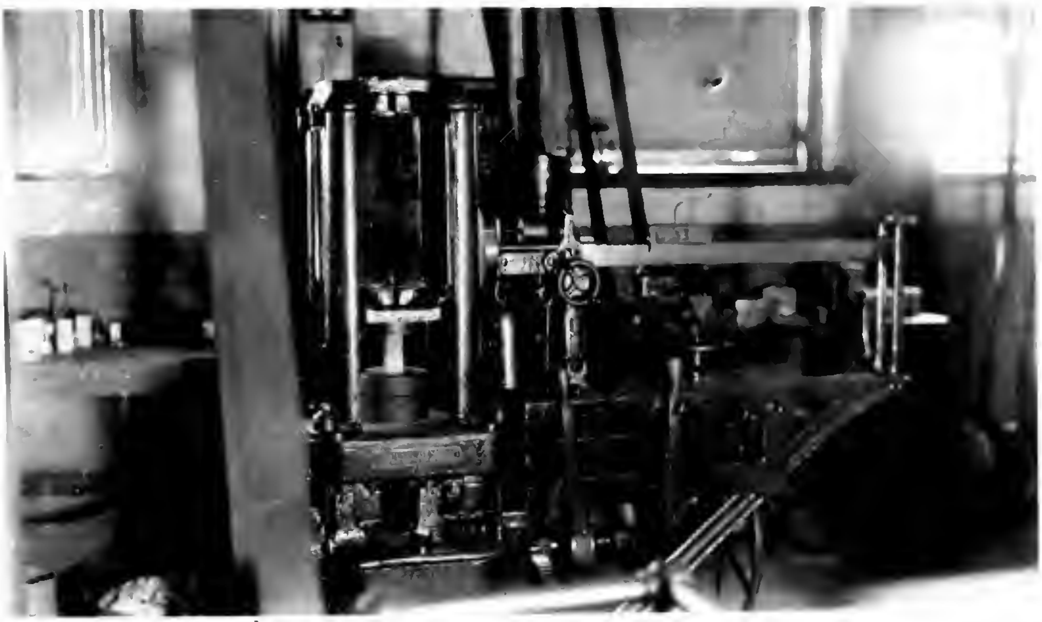
The usual practice for compression test is to have one inch cubes as the test pieces, but it was thought that the cylinders would give better results. When these cylinders are under compression, a column action and shearing stress developes.

The machine for testing the briquettes was a 1000 pound Riehle shot testing machine as shown on page (23).

The cylinders were tested in a 60,000 pound motor driven testing machine, manufactured by Tinius Olsen & Co., as shown on page (25).

The cylinders were placed on a spherical compression block, and between two blotters so that the pressure would be more evenly distributed. On page 25 to 30 is shown the compressive and tensile strength of each mortar in pounds per square inch.

Tensile Testing Machine



Compression Testing Machine

Strength of 1:3 Mortars of Sample B.

Ungraded and Unwashed Sand B-1.

	Tensile strength in pounds per sq. in.			Percent. of Water	Compressive strength in pounds per sq.in.		
	7 days	28 days	90 days		7 days	28 days	90 days
(1)	231	392	399	10.0	1210	880	2415
(2)	301	340	295		760	1370	2430
(3)	200	250	429		670	1120	1720
(4)	226	367	368		775	1690	1840
mean	239	340	375		855	1260	2100

Ungraded and Washed Sand B-2.

	Tensile strength in pounds per sq. in.			Percent. of Water	Compressive strength in pounds per sq.in.		
	7 days	28 days	90 days		7 days	28 days	90 days
(1)	243	451	462	9.6	2060	3420	3170
(2)	329	428	390		1335	2230	2960
(3)	235	385	544		705	2675	3600
(4)	278	370	371		....	2720	3240
mean	271	409	442		1430	2770	3240

Graded and Washed Sand B-3.

	Tensile strength in pounds per sq. in.			Percent. of Water.	Compressive strength in pounds per sq.in.		
	7 days	28 days	90 days		7 days	28 days	90 days
(1)	333	385		9.6	1975	3850	
(2)	365	347			1850	3540	
(3)	329	350			2020	2020	
(4)	360	450	———		....	1940	———
mean	348	382			1615	2825	

Strength of 1:3 Mortar of Sample C.

Ungraded and Unwashed Sand C-1.

	Tensile strength in pounds per sq. in. 7 days	28 days	90 days	Percent. of water	Compressive strength in pounds per sq.in. 7 days	28 days	90 days
(1)	279	358	496		1285	1355	1335
(2)	324	510	558	10.6	1720	2420	2880
(3)	298	473	589		1465	1920	2770
(4)	300	474	566		1070	1640	2240
mean	305	454	552		1380	1835	2300

Ungraded and Washed Sand C-2.

	Tensile strength in pounds per sq. in. 7 days	28 days	90 days	Percent. of water	Compressive strength in pounds per sq.in. 7 days	28 days	90 days
(1)	353	504	570		1200	1970	2850
(2)	310	473	584	9.6	2380	1910	2100
(3)	275	510	570		1620	2200	2760
(4)	...	460	556		....	1900	2480
mean	312	487	570		1700	1995	2550

Graded and Washed Sand C-3.

	Tensile strength in pounds per sq. in. 7 days	28 days	90 days	Percent. of water	Compressive strength in pounds per sq. in. 7 days	28 days	90 days
(1)	378	465			2080	2860	
(2)	377	452		9.6	1960	2910	
(3)	353	632			2080	3390	
(4)	...	535	———		....	....	———
mean	369	520			2040	3090	

Strength of 1:3 Mortars of Sample D.

Ungraded and Unwashed Sand D-1.

	Tensile strength in pounds per sq. in.			Percent. of water	Compressive strength in pounds per sq.in.		
	7 days	28 days	90 days		7 days	28 days	90 days
(1)	309	455	558		1550	2390	2580
(2)	289	492	611	10.0	1380	2470	3340
(3)	320	433	511		1620	2580	3590
(4)	...	...	524		1280	....	3180
mean	306	460	551		1440	2480	3170

Washed and Graded Sand D-3.

	Tensile strength in pounds per sq. in.			Percent. of water	Compressive strength in pounds per sq. in		
	7 days	28 days	90 days		7 days	28 days	90 days
(1)	250	408	379		935	955	1000
(2)	203	390	437	9.6	1920	925	1620
(3)	298	307	342		870	875	1720
(4)	...	...	360		775	1040	1270
mean	247	369	379		875	950	1400

Strength of 1:3 Mortars.

Ungraded and Unwashed Sand Sample E-1.

Tensile strength in pounds per sq. in.				Percent. of water	Compressive strength in pounds per sq.in.		
	7 days	28 days	90 days		7 days	28 days	90 days
(1)	213	272	316	9.8	1080	1270	2080
(2)	230	339	358		925	915	2140
(3)	161	304	368		910	1020	1760
(4)	221	264	...		1140	940	2010
mean	206	294	347		1010	1040	1990

Ungraded and Unwashed Sand Sample F-1.

Tensile strength in pounds per sq. in.				Percent. of water.	Compressive strength in pounds per sq.in.		
	7 days	28 days	90 days		7 days	28 days	90 days
(1)	270	336	362	9.9	1220	1190	2260
(2)	190	348	340		945	1460	2310
(3)	225	340	359		1030	1030	2710
(4)	205	...	350		1310	1270	2540
mean	222	341	353		1120	1240	2460

Ungraded and Unwashed Sand Sample G-1.

Tensile strength in pounds per sq. in.				Percent. of water.	Compressive strength in pounds per sq. in.		
	7 days	28 days	90 days		7 days	28 days	90 days
(1)	148	226	235	10.2	450	870	1420
(2)	138	230	210		273	1040	1120
(3)	96	219	190		382	1080	1280
(4)	145	165	243		425	1100	1660
mean	131	210	219		382	1070	1370

Strength of 1:3 Mortar of Sample H.

Ungraded and Unwashed Sand H-1.

	Tensile strength in pounds per sq. in.			Percent. of water	Compressive strength in pounds per sq. in.		
	7 days	28 days	90 days		7 days	28 days	90 days
(1)	258	295	332	9.6	1130	860	1920
(2)	206	294	336		1220	1175	1120
(3)	212	269	315		965	1380	1680
(4)	225	330	328		650	1090	1900
mean	225	297	327		991	1126	1650

Ungraded and Washed Sand H-2.

	Tensile strength in pounds per sq. in.			Percent. of water	Compressive strength in pounds per sq. in.		
	7 days	28 days	90 days		7 days	28 days	90 days
(1)	254	304	358	9.8	1280	1745	2540
(2)	233	330	340		1430	1400	2550
(3)	248	298	325		800	1020	2160
(4)	244	320	...		930	2110	2690
mean	244	313	341		1110	1568	2480

Graded and Washed Sand H-3.

	Tensile strength in pounds per sq. in.			Percent. of water	Compressive strength in pounds per sq. in.		
	7 days	28 days	90 days		7 days	28 days	90 days
(1)	194	247		9.6	1380	1260	
(2)	202	433			865	1180	
(3)	213	219			770	1535	
(4)	184	250			...	1520	
mean	198	287	——		1005	1374	——

Strength of 1:3 Mortar of Sample I

Ungraded and Unwashed Sand I-1.

	Tensile strength in pounds per sq.in.				Compressive strength in pounds per sq.in.		
	7 days	28 days	90 days	Percent. of water	7 days	28 days	90 days
(1)	251	302	260		1120	1290	1310
(2)	216	195	349	9.6	1360	1390	1420
(3)	191	272	276		530	1290	1550
(4)	...	303	300		720	1180	....
mean	219	268	296		940	1290	1420

Ungraded and Washed Sand I-3.

	Tensile strength in pounds per sq. in.				Compressive strength in pounds per sq. in.		
	7 days	28 days	90 days	Percent. of water	7 days	28 days	90 days
(1)	300	408			2110	3820	
(2)	278	456		9.6	2250	3800	
(3)	310	438			1730	3190	
(4)	273	439			1445	....	
mean	290	435	——		1885	3600	——

Specific Gravity

The specific gravity of the sand was determined in a graduated cylinder one inch in diameter, and having a capacity of 100 c.c. The graduate was partly filled with water, and the height of the column of water in the stem was read. Fifty grams of moisture free sand was admitted, care being taken to permit the escape of air, and then the new height of the column of water was read. The difference between the two readings gave the volume of water displaced by 50 grams of sand. The specific gravity was then calculated by finding the ratio between the weight in grams of the sand and the volume of water displaced in cubic centimeters.

$$\text{Sp. Gr.} = \frac{\text{Weight of sand}}{\text{Volume of water displaced}}$$

The value of determining the specific gravity of the sand is a means in computing the percentage of voids. On page (35) is shown the mean of three determinations.

Percentage of Voids.

The percentage of voids test is made by determining the proportion of the total volume of a sample of sand which is taken up by air lying between the grains. The proportion of voids may be determined by filling a vessel with a known quantity of water, and then determining the amount of sand that can be poured into the vessel with the water.

In determining the percentage of voids, a graduated glass cylinder about 1 inch in diameter, and 100 c.c. capacity was used. A known quantity of water was poured into the vessel, and the weight of the vessel and water taken. Moisture free sand was slowly poured into the water in order to allow the air bubbles to escape. The sand was then compacted by gently striking the bottom of the cylinder on a pad of cloth, composed of several thickness of heavy flannel. The sand was poured in increments until the top surface of the water and the sand was at the same level. The amount of sand used

was found by reading the height of the surface of the sand.

The percentage of voids was then calculated by dividing the quantity of water in the vessel with the sand by an amount of water whose volume was the same as the volume of the sand used. Corrections were made for the percent of absorption.

The percent of voids also may be determined by dividing the weight per cubic foot of the loose material by the product of the specific gravity of the sample and the weight of a cubic foot of water.

The great difficulty in making this test is that of securing a uniform degree of compactness of the sample in the container in which the volume is measured. The sample was allowed to compact very much as the particles in mortar are compacted. The sand should not drop through any considerable depth of water, as there is a liability that the sand may become separated into strata having a single size of grains in each, in which the voids

would be greater than if the several sizes were thoroughly mixed.

With the same sample of sand, by simply varying the method of filling the container, it is possible to have a variation in results as great as 25 percent. There is another shortcoming of this test, and that is the information obtained applies only to the sand when alone, unmixed with cement. What is really wanted is a knowledge of the actual space occupied by the sand in a unit volume of mortar, wherein each sand grain is separated from its neighbor by a layer of cement.

Until a constituent standard method of determining voids has been devised and adopted, this test has little particular value. The test therefore at present usually employed in the routine testing of sand leads to erroneous conclusions. The mean of three determinations is shown in the table on page (35).

Specific Gravity, Weight per Cubic Foot and Voids.

Sample	Percent Moisture	of Specific Gravity	Weight per cubic foot pounds	Percent of Voids	
				Meas-ured	calcu-lated.
A	0.25	2.66	106.12	34.6	36.2
B	0.40	2.70	112.46	32.2	33.5
C	0.77	2.50	115.21	34.4	26.0
D	0.37	2.50	103.90	36.6	33.0
E	2.32	2.60	87.30	33.8	46.0
F	2.75	2.65	98.95	32.7	40.0
G	2.25	2.66	87.50	36.2	47.5
H	5.32	2.68	105.00	39.7	37.0
I	1.43	2.68	99.80	31.3	40.3

Percentage of Silt.

The sand was tested for cleannes as follows: 500 grams of moisture free sand was thoroughly agitated in a vessel containing about 1/2 gallon of water. The sand was agitated by stirring it until the silt came to the surface of the water. The finer sand particles were allowed to settle, this process requiring only two minutes. The dirty water was siphoned off with a 1/4 inch rubber tube, care being taken that none of the sand was carried off with the water. This washing process was repeated until the water showed no discoloration. The time required for this washing varied from about 15 minutes for fairly clean sand to 2 hours for the dirtiest sand. As much water as possible was then drawn off, and the remainder was slowly evaporated and the sand thoroughly dried. The sand was then weighed, and the loss in weight due to washing was taken as the amount of suspended matter. The mean of 3 determinations is shown on page (38).

Effect of Impurities in Sand.

Foreigh material in sand may affect the strength of the mortar by retarding or preventing the hardening of the cement, and also preventing the adhesion of the cement to the sand grains. Organic matter is the most common source of trouble, and sometimes clay and loam will decrease the strength of mortar.

It has been found from various experiments, that the addition of a small amount of finely pulverized clay has no effect on the strength of a lean mixture of mortar. The amount of clay that can be added to the sand depends upon the percent of fine particles in the sand. A sand containing a small percent of fine particles will require a larger amount of clay. The addition of clay will decrease the percent of voids and increase the density of the sand. Clay makes the mortar more watertight and easier to work.

Organic matter will always decrease the strength of mortar, as there are certain chemical actions between the cement and the impurities of the sand.

As would be expected, the sands that are pumped from the bottom of rivers and lakes have the smallest percentage of silt, and bank sand next. On page (25 to 30) is shown the results of the strength tests of washed and un-washed sand.

Percentage of Silt

Sample	%	Kind of Sand
A	Trace	20-30
B	9.5	Bank
C	6.0	Bank
D	0.0	Granite Screening
E	Trace	Hydraulic sand
F	0.1	Hydraulic sand
G	0.3	Lake Sand
H	11.2	Bank
I	0.3	River

Granulomctric Analysis

The sand used in all the tests consists of particles smaller than one-quarter of an inch in diameter. As soon as a sample was received, it was placed on a one-quarter inch sieve and thoroughly shaken, and also the percent of moisture and the weight per cubic foot were obtained. The residue retained on this sieve was discarded. The sand then was thoroughly dried.

A granulometric or mechanical analysis is to show the composition of the sand as to the proportion of the different sized particles contained in the sample. The granulometric analysis is made by passing the sand through a series of successive sizes of wire screens. The material then may be represented by a curve whose ordinates are the percentages by weight which passes a sieve, and the abscissas represents the diameter of the particles in inches.

The apparatus used in the sieve analysis was

a Howard & Morse power sifter. It consists of a nest of standard sieves, the screens being made of woven brass wires. The openings of the sieves are: 10, 20, 30, 40, 50, 60, 80, 100 and 200 meshes to a lineal inch. Each sieve is 2 1/4 inches high and 8 inches in diameter. The sieves were nested in the order named in the following table; the largest sieve being at the top. While the apparatus is in operation, the sieves are given a rotary motion, and at the same time a violent vertical bumping motion.

The following table gives the diameter of the openings of the sieves used in the granulometric analysis.

Sieve Number	Diameter of openings in inches	
#10	0.073	inches
#20	0.034	"
#30	0.022	"
#40	0.015	"
#50	0.011	"
#60	0.009	"
#80	0.007	"
#100	0.0045	"
#200	0.00275	"

Washed sand was used in making the granulometric analysis, as I wished to use the washed sand in combining the particles to form the mortar having the maximum density. Five-hundred grams of moisture free sand was placed on the top sieve, and the whole nest shaken for twenty minutes at 100 r.p.m. After the sand had been shaken, the amount retained on each sieve was weighed, care being taken that all the particles were taken off the sieve.

The granulometric curves are shown on page 45 to 52. The ordinates are the percentage by weight passing a given sieve, and the abscissas represents the diameter of the particles in inches. In order to find the percentage passing any sieve, it is necessary to add the percents retained on the smaller sieves. It is seen from the table for the sieve analysis of sample B page (43), that adding the percents retained on the #80, #100, #200 sieves and the pan, will give the percent passing the #60 sieve (2.67+ 1.52

+ 2.10 + 1.57 = 7.86) In like manner the percents passing the other sieves are obtained. The percent is given in terms of the amount of the sample used (500 grams).

The following is an analysis of Sample B.

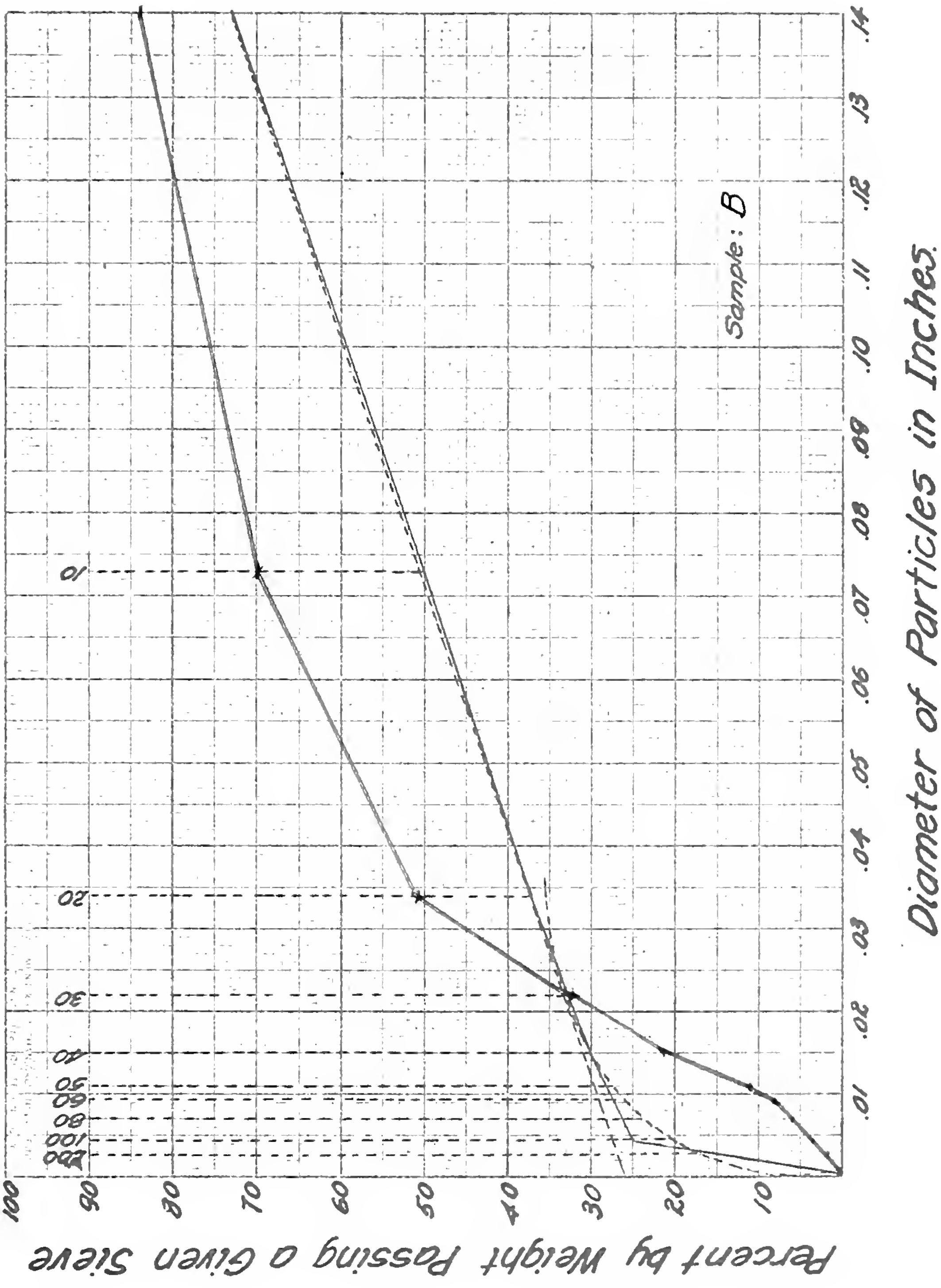
Sieve	Amount Retained	Percent Retained	Amount Passing	Percent Passing
#10	150.6	30.12	349.4	69.88
#20	95.3	19.06	254.1	50.82
#30	90.35	18.17	165.25	32.65
#40	57.6	11.52	105.65	21.13
#50	51.65	10.33	54.0	10.80
#60	14.7	2.94	39.3	7.86
#80	13.35	2.67	25.95	5.91
#100	7.6	1.52	18.35	3.67
#200	10.5	2.10	7.85	1.57
pan	7.85	1.57		

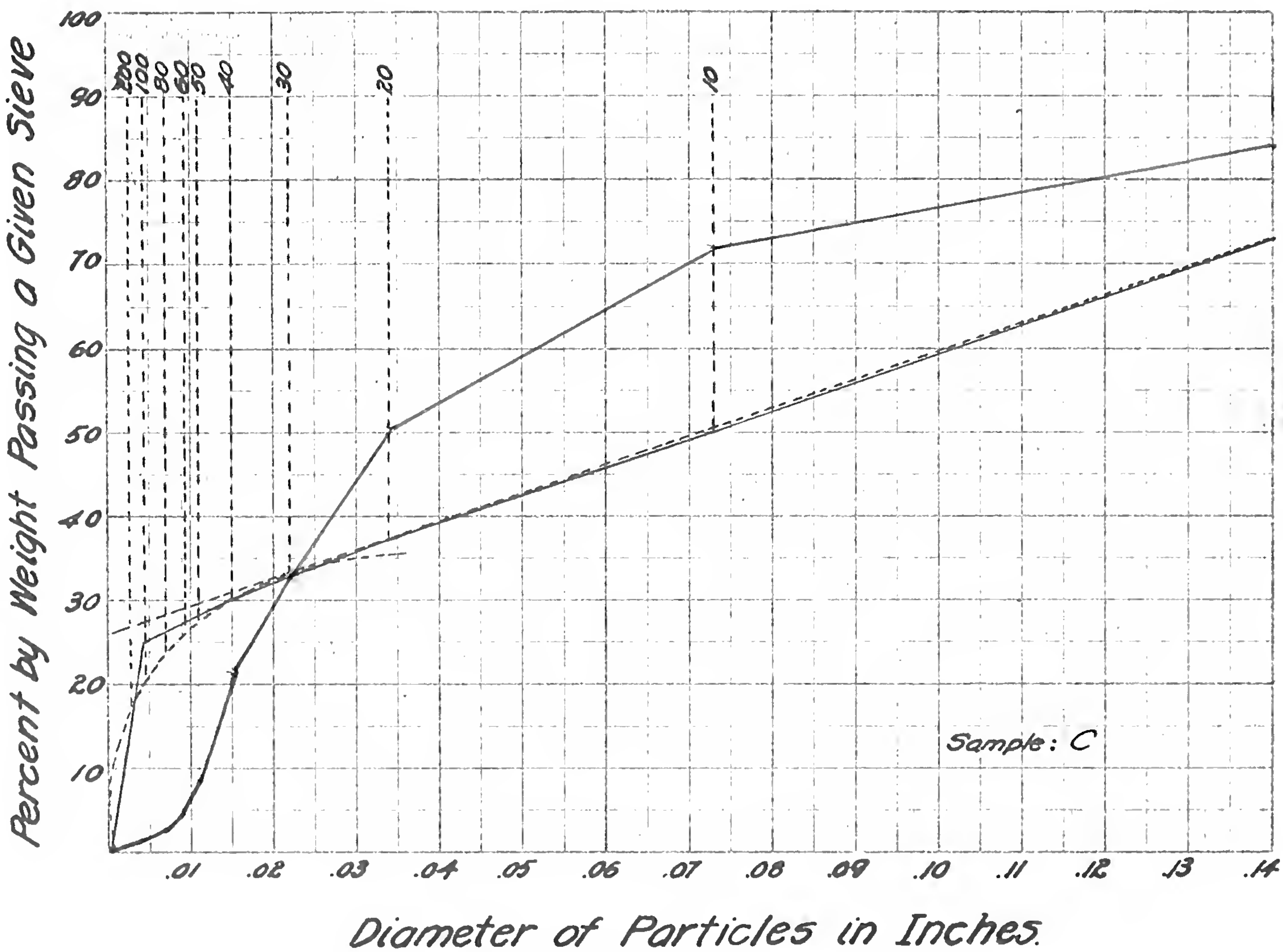
By plotting the percent passing a given sieve, against the diameter of particles, and connecting the points, we get the sieve analysis curves as shown on page(45 to 52). The dotted line is the ideal curve for a mortar having the maximum density. This curve is a combination of a straight line and ellipse. (The construction of this is explained on page (53 to 61).

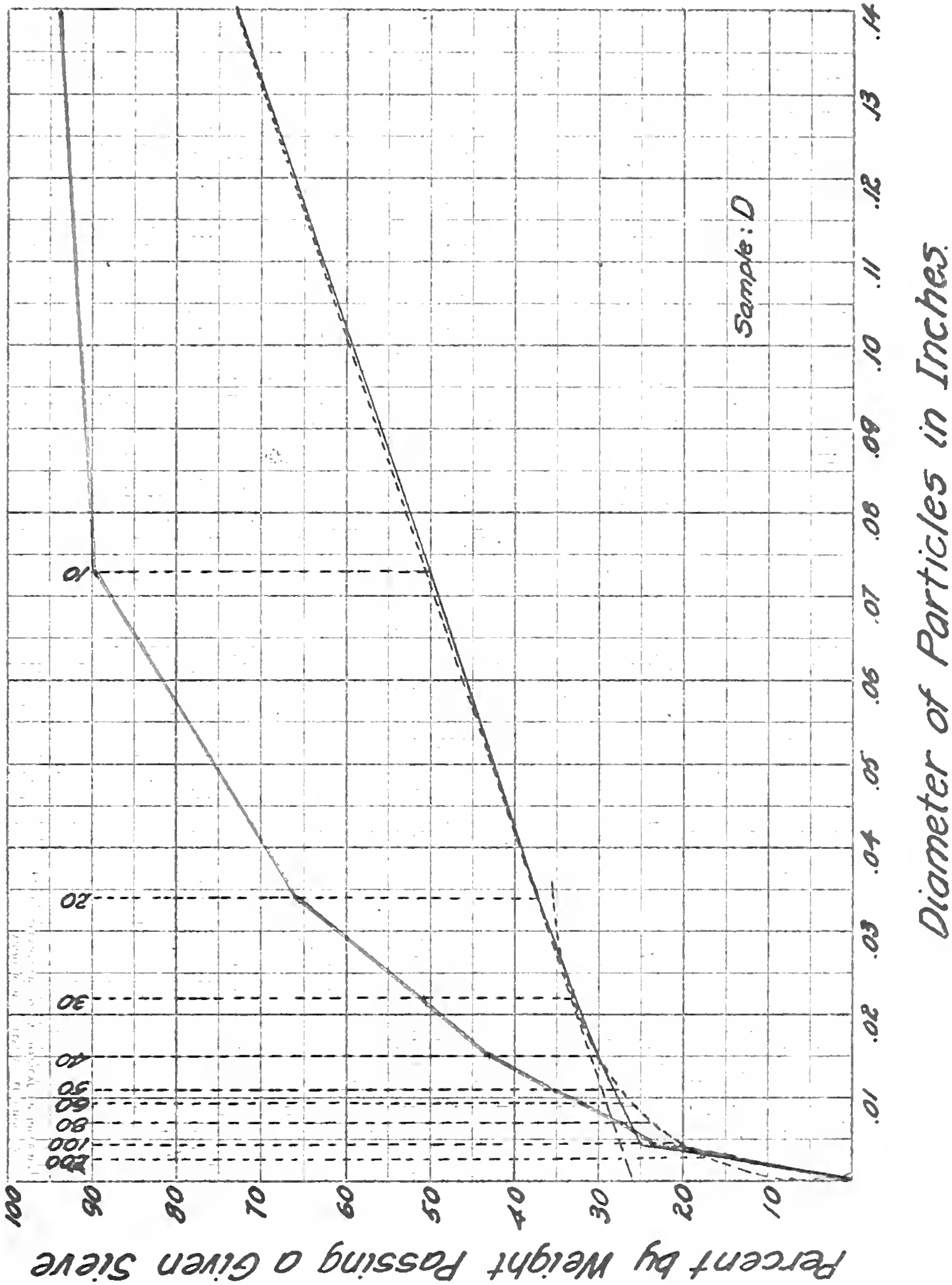
Sieve Analysis

	Percent by Weight Passing Sieve No.								
Sample	10	20	30	40	50	60	80	100	200
B	69.98	50.82	32.65	21.13	10.80	7.86	5.91	3.67	1.57
C	71.80	50.42	33.37	21.42	8.33	4.68	2.29	1.28	0.43
D	89.35	66.11	50.64	43.00	35.21	31.53	27.06	23.51	14.25
E	97.51	89.53	68.41	53.75	37.00	26.65	10.94	4.93	1.30
F	96.61	84.83	59.97	47.53	36.67	29.28	11.91	4.28	2.20
G	100.00	99.77	99.61	96.83	91.29	69.75	40.78	4.25	2.54
H	80.06	59.10	43.44	32.06	19.96	8.68	3.28	1.20	0.22
I	95.77	81.87	62.86	24.90	5.14	3.88	1.18	0.79	0.41

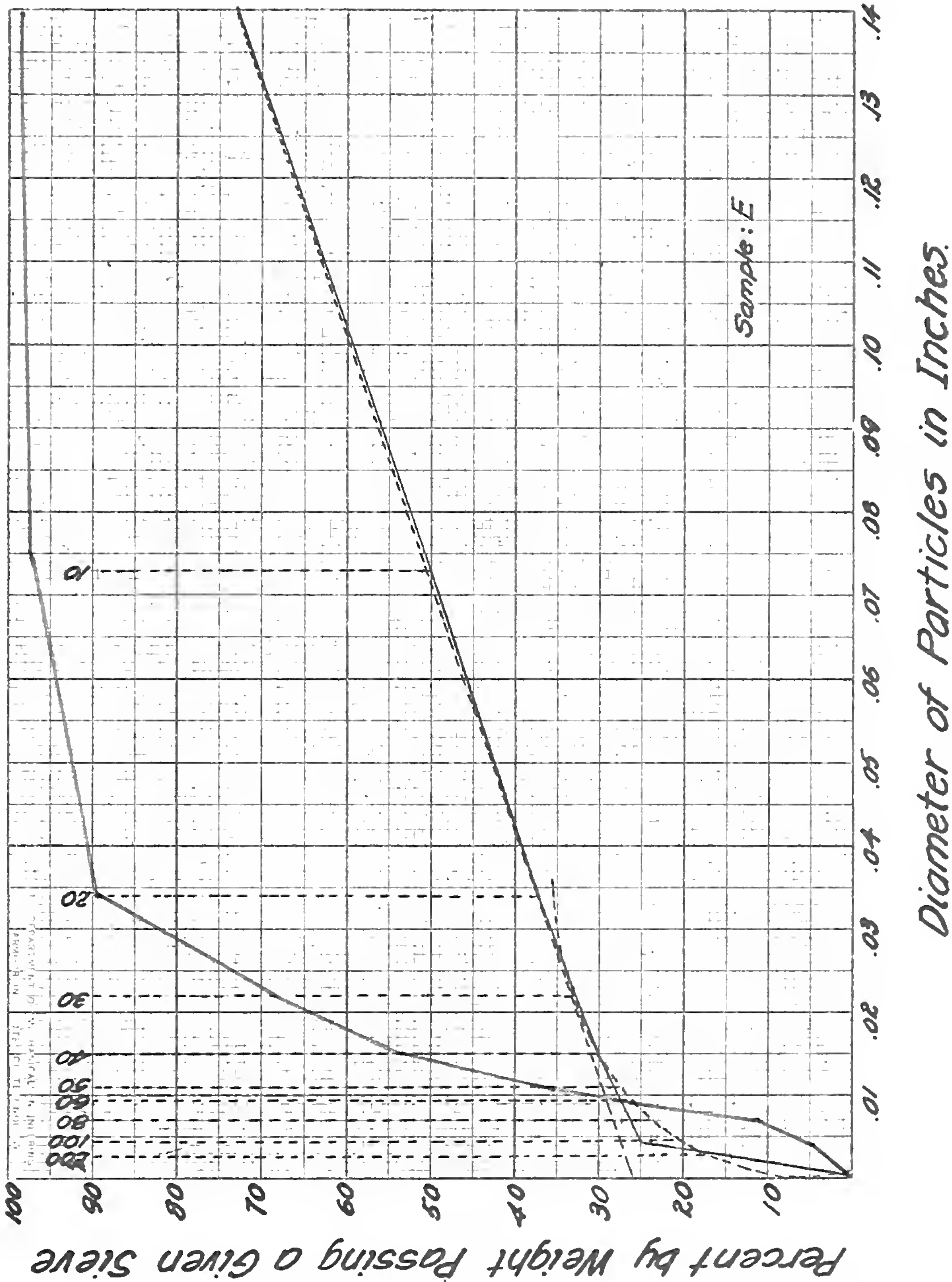
Power Sieves.


Sample: B
Diameter of Particles in Inches
Percent by Weight Passing a Given Sieve
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
10
20
30
40
50
60
70
80
90
100
200

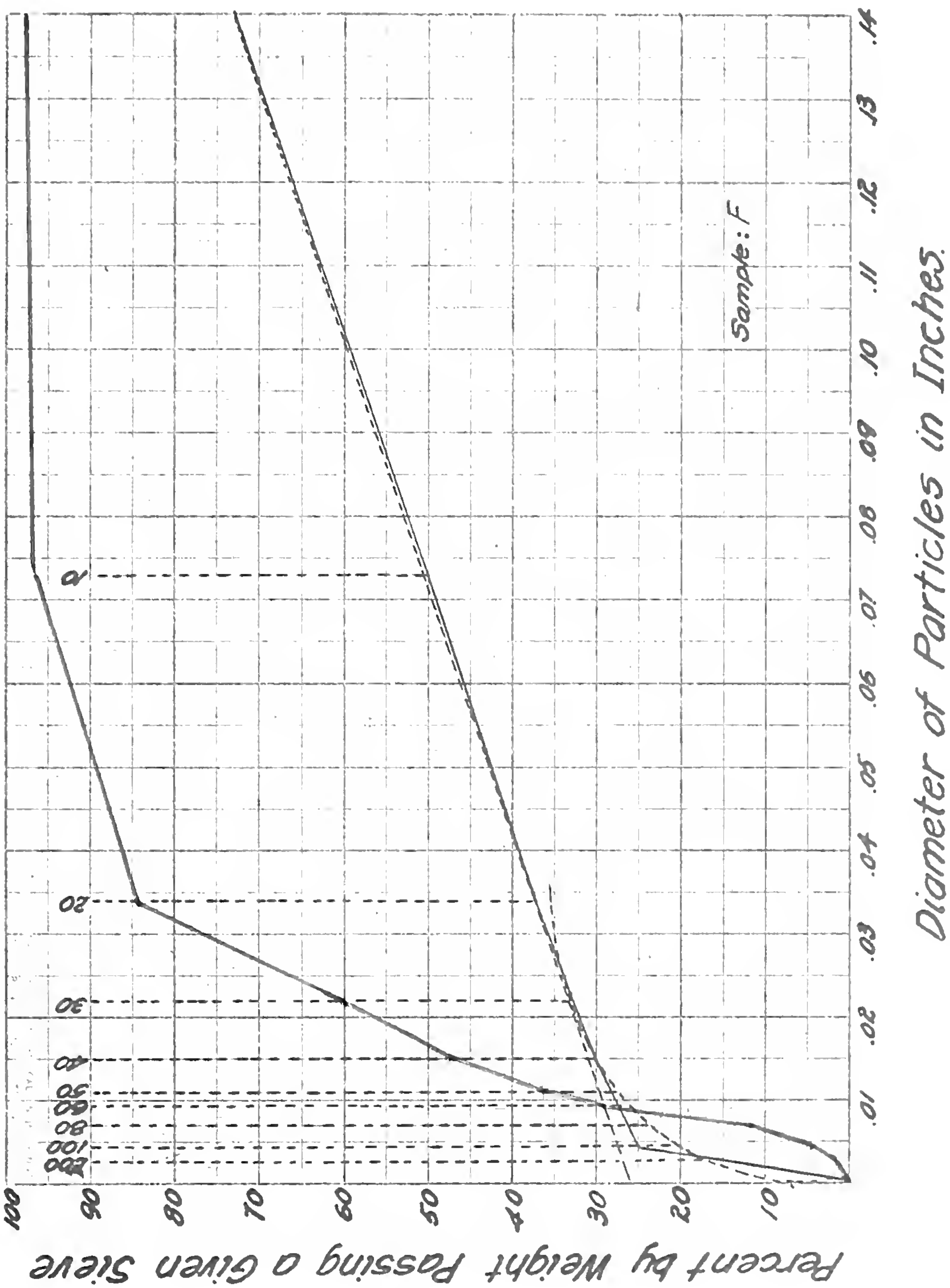

Percent by Weight Passing a Given Sieve
100
90
80
70
60
50
40
30
20
10
200
100
80
60
50
40
30
20
10
Sample: C
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
Diameter of Particles in Inches

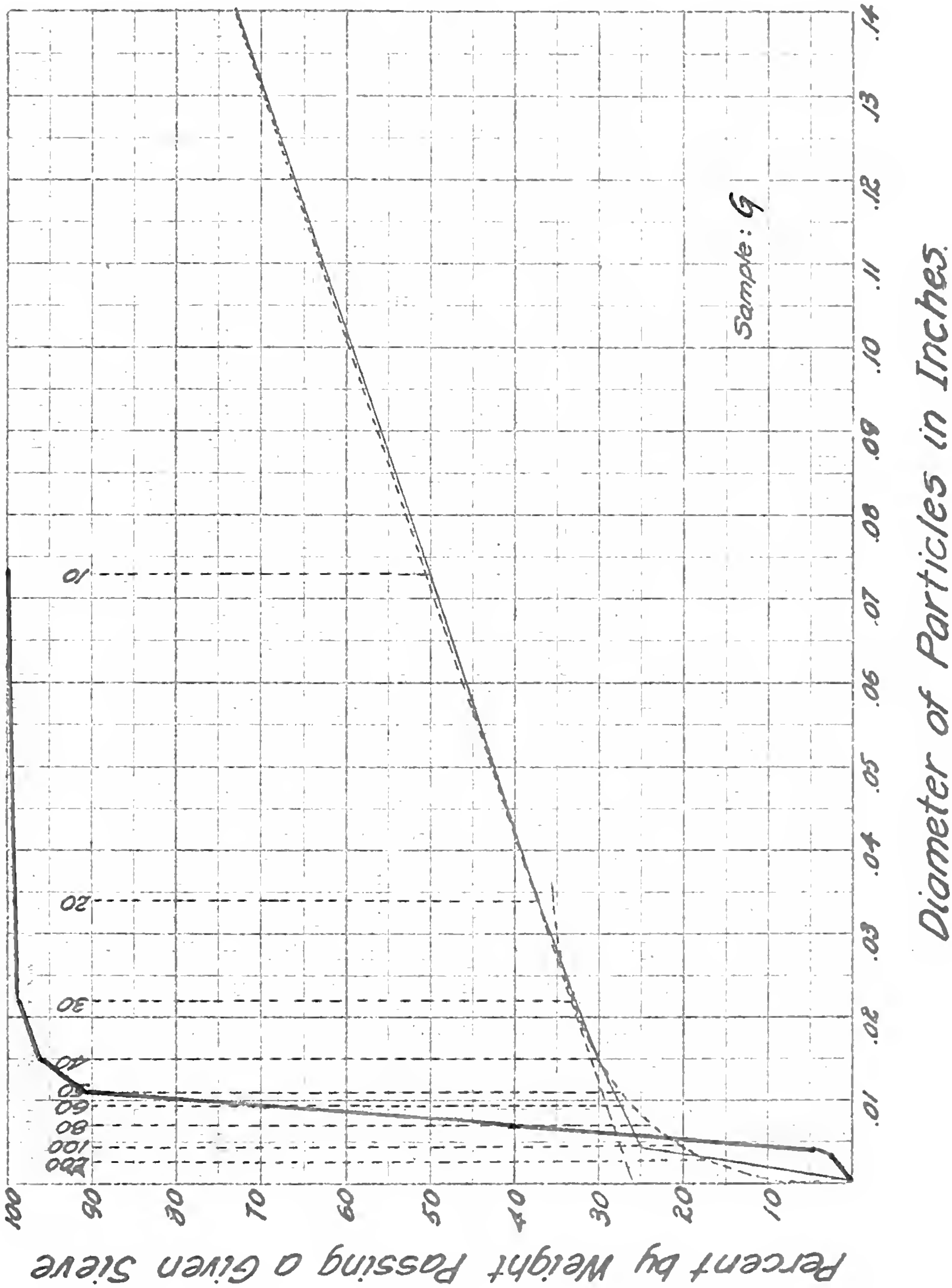


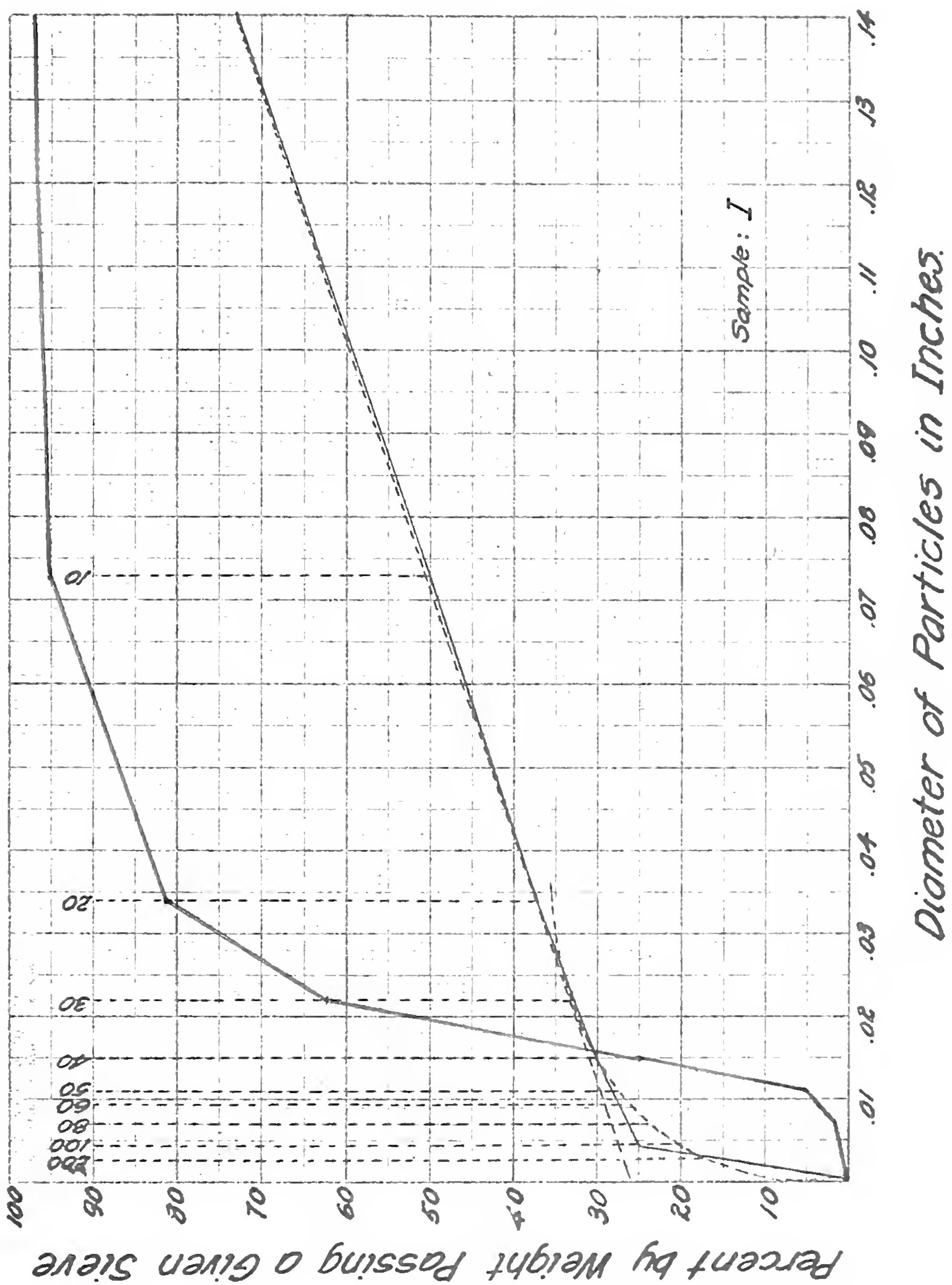
Sample: D
Diameter of Particles in Inches
Percent by Weight Passing a Given Sieve
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
100
90
80
70
60
50
40
30
20
10

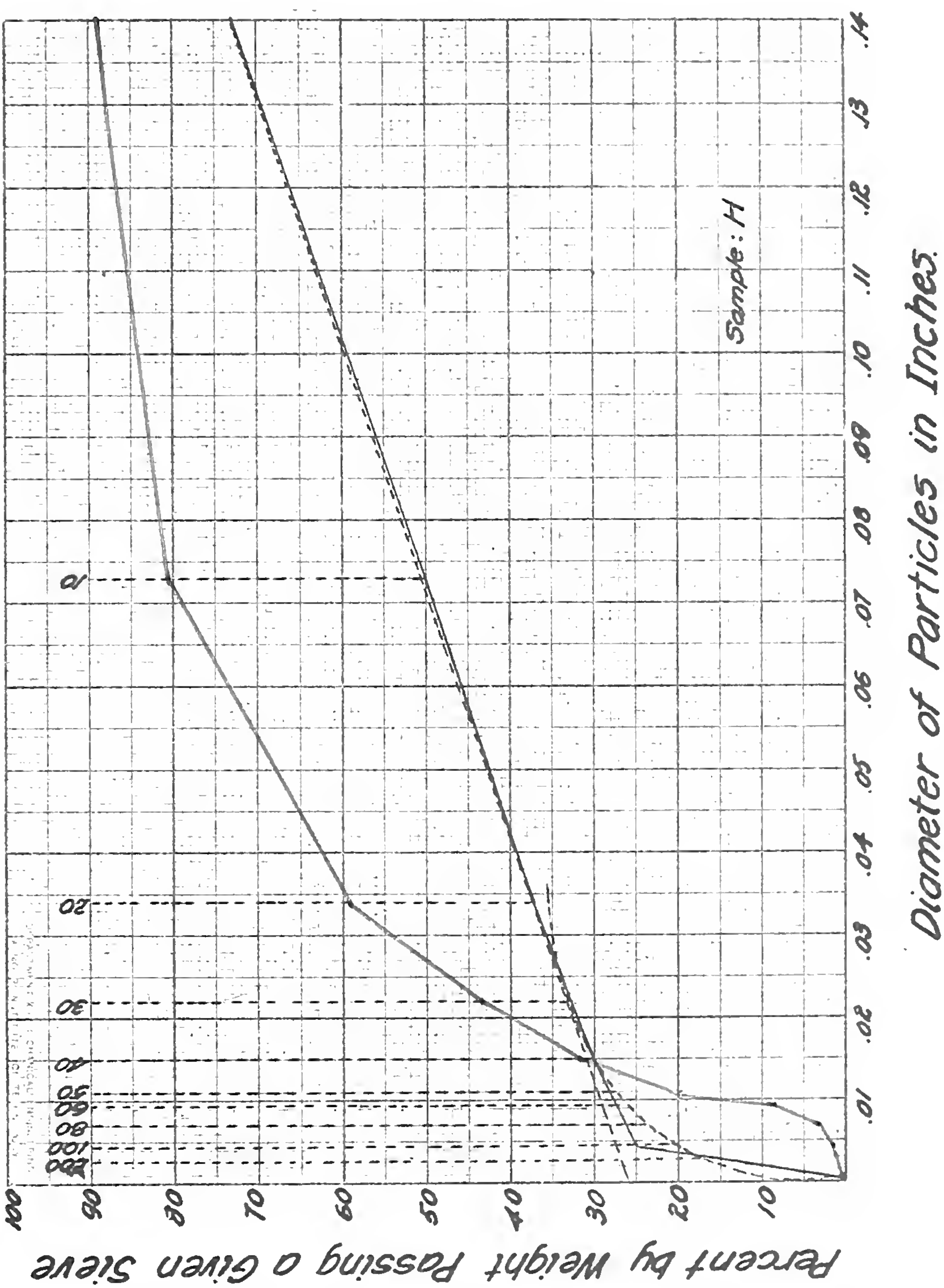


Sample: E
Diameter of Particles in Inches
Percent by Weight Passing a Given Sieve
.01 .02 .03 .04 .05 .06 .07 .08 .09 .10 .11 .12 .13 .14
10 20 30 40 50 60 70 80 90 100
10
20
30
40
50
60
80
100
200


Sample: F
Diameter of Particles in Inches
Percent by Weight Passing a Given Sieve
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
10
20
30
40
50
60
70
80
90
100
10
20
30
40
50
60
80
100
200


Sample: G
Diameter of Particles in Inches
Percent by Weight Passing a Given Sieve
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
10
20
30
40
50
60
70
80
90
100
10
20
30
40
50
60
70
80
90
100
200


Sample: I
Diameter of Particles in Inches
Percent by Weight Passing a Given Sieve
.01 .02 .03 .04 .05 .06 .07 .08 .09 .10 .11 .12 .13 .14
10 20 30 40 50 60 70 80 90 100
10 20 30 40 50 60 80 100 200


Sample: H
Diameter of Particles in Inches
Percent by Weight Passing a Given Sieve
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
10
20
30
40
50
60
70
80
90
100

Proportioning and Combining the Sample by Means of Sieve Analysis Curve Similar to Fuller's Curve for Maximum Density.

Proportioning by sieve analysis consists of separating the particles of the sample into various sizes of which it is composed, and recombining the particles in the proper proportion, in order to form a mortar that will have a maximum density.

The object of a sieve analysis as applied to mortar and concrete is:-

1. To show graphically the sizes and relative size of the aggregate.

2. To indicate what sizes are needed to make the sample more nearly perfect in order to improve it by the addition or subtraction of some of the different size aggregate.

It has been shown from experiment that mortar or concrete, having the maximum den-

sity will give the greatest breaking strength. In a series of experiments carried out by Wm. B. Fuller, at the Jerome Park Reservoir, it was shown, that the highest breaking strength of concrete, is made from an aggregate whose sieve analysis, taken after mixing the sand and stone, form a curve that consists of a straight line and an ellipse.

Construction of the curve for maximum density or ideal curve: First a straight line should be drawn from the point where the diameter of the largest particles reaches the 100 per cent line; to a point on the vertical ordinate at zero diameter, which is given in column (I) in the following table.

(a) and (b) are given in column (3) and (4) of the above table. The ellipse is tangent to the vertical ordinate through zero, and the point of tangency is at the intersection of the major axis and this ordinate.

Fuller's ideal curve for maximum density, was used for concrete and did not include the cement particles that are smaller than a #100 sieve. This curve was drawn for a mixture of stone and sand, and the size of the aggregate ranging from the maximum size stone down to the particles retained on the #100 sieve. In my work, I assumed that the ideal curve included the cement particles, which are taken to be finer than the #100 sieve. The ideal curve is made up of cement and sand. The size of the sand particles

Data for Plotting the Ideal Curve.

Material	Intersection of tangent with vert.at zero diam. (1)	Height of tangent Point. (2)	Axis of Ellipse (a) (3)	(b) (4)
Crushed Stone and Sand	28.5	35.7	0.150 D	37.4
Gravel and Sand	26.0	33.4	0.164 D	35.6
Crushed Stone and Screenings	29.0	36.1	0.141 D	37.8

D = Maximum diameter of the particles.

This line is tangent to an ellipse; the point of tangency is where this line intersects a vertical ordinate for one-tenth maximum size diameter particle. This point of tangency should check for the value given in column (2).

The equation for the ellipse

$(Y - 7)^2 = (b/a)^2(2\ ax-x^2)$. The major axis of the ellipse should coincide with the 7 per cent line of percentage. The values of

used for the mortar having the maximum density should all pass the #4 sieve and be retained on the #100 sieve.

In plotting the curve, I took the data required for gravel and sand, from the above table. The tangent line intersects the zero ordinate at 26.0. The ellispe is tangent to this line at .022 which is 1/10 the maximum size aggregate. The height of the tangent point is 33.4. The largest size aggregate (D) was taken equal to .22 inches. The values of the major and minor axis are taken from the table as 0.164 D and 35.6 respectively. The ideal curve is plotted as above explained, but as I wish to use a mortar having a ratio of one part of cement to three parts of sand by weight; the sieve analysis curve for such a combination will not coincide with the ideal curve.

If we take all the cement particles as finer than the #100 sieve, it is seen from the ideal curve on page (55) that 20 per cent of the combination of cement and sand is finer than the #100 sieve. In the mixture that I used, 25 per cent of the combination consisted of cement, and this is 5 per cent more than necessary to have an ideal mixture.

By taking all the cement as finer than the #100 sieve, we therefore will have a point on the curve for this combination of sand and cement. All the sand is retained on the #100 sieve and passes the #4 sieve. On page(45 to 52) the dotted line represents the ideal sieve analysis curve which contains 20 per cent cement, and the fine line is so arranged that it will approach the ideal curve as near as possible and this represents the sieve analysis

curve for a combination of sand and cement which contains 25 per cent cement. This curve coincides with the ideal curve at the point where the ordinates for the #40, #30, #20, and #4 sieves cross the ideal curve. From this curve, the percent passing each sieve is shown in the table below.

Sieve	percent passing
#4	100.00
#10	50.00
#20	37.50
#30	33.50
#40	30.00
#50	28.50
#60	27.00
#80	26.00
#100	25.00

In order to find the percent retained on any given sieve for this combination, it is necessary to subtract from the percent passing through the next largest sieve, the percent

passing the sieve under consideration. E.G. It is seen that 50.00 percent passes the #10, and 37.50 per cent passes the #20 sieve, therefore 50.00 - 37.50 = 12.50 per-cent is retained on the #20 sieve. In like manner the per-cent retained on each sieve is obtained. In column (3) the per-cent retained on each sieve is given.

The following table gives the amount and per-cent retained on and passing each sieve in order to have a combination of sand and cement where sieve analysis will approach the ideal curve. The mortar is made in batches of 1000 grams, and the following table shows the relation of the particles in the dry mortar for each batch.

(1) Sieve	(2) Amount Retained	(3) Percent Retained	(4) Amount Passing	(5) Percent Passing
#4	000.00	00.00	1000.00	100.00
#10	500.00	50.00	500.00	50.00
#20	125.00	12.50	375.00	37.50
#30	40.00	4.00	335.00	33.50
#40	35.00	3.50	300.00	30.00
#50	15.00	1.50	285.00	28.50
#60	15.00	1.50	270.00	27.00
#80	10.00	1.00	260.00	26.00
#100	10.00	1.00	250.00	25.00
pan	250.00	25.00		

The above table was tabulated for a combination of cement and sand in the ratio of one part of cement to three parts of sand, but it is necessary in order to combine the different size sand particles, to determine the percent passing and retained on each sieve, in terms of the amount of sand. The following table gives the amount and percent passing and retained on each sieve, when 750 grams of sand are used. Each batch of mortar contains 250 grams of cement and 750 grams of sand. The

amount retained on each sieve is taken from the preceding table, and the remainder of the following table is completed as explained under granulometric analysis page 39.

(1) Sieve	(2) Amount Retained	(3) Percent Retained	(4) Amount Passing	(5) Percent Passing.
#4	000.00	00.00	750.00	100.00
#10	500.00	66.66	250.00	33.34
#20	125.00	16.67	125.00	16.67
#30	40.00	5.37	85.00	11.37
#40	35.00	4.66	50.00	6.66
#50	15.00	2.00	35.00	4.66
#60	15.00	2.00	20.00	2.66
#80	10.00	1.33	10.00	1.33
#100	10.00	1.33	00.00	0.00
pan	00.00	0.00		

On page (   ) is shown the sieve analysis curve for the ideal sand. The curve for the cement will be a straight line connecting the origin with the point where the ordinate for the #100 sieve crosses the 100 per cent line of percentage. The ideal curve is a combination of the sand curve and the cement curve.

In order to expedite the work in the laboratory, the sand is not collected on all the sieves. In most of the samples, the particles were collected on the #10, #20, #40, and #100 sieves, but a few samples had such a small percent retained on the larger sieves, that it was necessary to collect the sample on the #30, #40 and #100 sieves. The sieve analysis curve in both cases will be the same. In column (2) of the following table shows the amount of sand to be retained on the #10, #20, #40 and #100 sieves respectively, when 750 grams of sand are used. The sand passing the #100 sieve is discarded.

(1) Sieve	(2) Amount Retained	(3) Percent Retained	(4) Amount Passing	(5) Percent Passing.
#10	500.00	66.66	250.00	33.34
#20	125.00	16.67	125.00	16.67
#40	75.00	10.00	50.00	6.67
#100	50.00	6.67	00.00	0.00

The sample was collected on the above sieves, and the different size particles were combined by weighing them out in the proper percentage, and adding them together. The amount of cement to be added in all cases will be 1/3 the weight of the graded sand. The graded sand was washed, as I did not want any clay or organic matter in the sand that would tend to act on the strength of the mortar.

As every sample of sand after being graded will follow the same sieve analysis curve, it will not be necessary to state the amount of the different size particles to be added or subtracted from each sample. On page (43) it is seen from sieve analysis table for sample B that: 30.12, 19.06, 29.69, 21.13 perdents are retained on the #10, #20, #40, and #100 sieves

respectively. In this sample there will be too small an amount of the particles retained on the #10 sieve. It will be necessary to add 66.66 - 30.12 = 36.54 percent, to the #10 particles. In like manner 2.39, 19.69, and 14.36 percent must be subtracted from the particles retained on the #20, #40, and #100 sieves.

Conclusion.

In closing this discussion, it is desired to emphasize that sand testing is yet in the formative stage. It has been endeavored to show the necessity of sand testing, by drawing the attention to certain properties of the sand that will go to make good concrete. Most of the tests made upon the samples of sand, do not bear directly upon the strength of the mortar produced. There are two tests that show if a sand is of good quality or not, the granulometric analysis and the test for cleanness.

The experiments illustrate the following facts:

1. Necessity of selecting clean sand.
2. Necessity of investigating sand deposits in order to determine its mineralogical composition.

3. Necessity of granulometric analysis.

4. Necessity of artificially grading sand on some sands.

5. No well defined relation exists between the strength of the mortar and the percentage of voids.

The effect of clean sand is well illustrated in all the strength tests, by comparing the strength of unwashed sand to washed sand. Sample B showed the greatest increase of strength, an increase after washing of 22% at an age of 28 days. The geological formation of sand deposits will vary widely, and the character of the sand grains depend upon the geological conditions. During the formations impurities will become mixed with the sand, the sand will disintegrate due to weathering; and other geological agents tend to be detrimental to the sand. When large quantities

of sand are to be used for construction purposes, it is necessary that an investigation of the sand deposits should be made, as the sand may have such impurities as clay, loam, silt and mica which affect the strength of mortar.

The granulometric analysis shows the composition of the sand as to the proportion of each size aggregate. The granulometric curves showed if it would be profitable to grade any particular sand according to the ideal curve, without wasting too much of the fine particals. The average sand is deficient in the coarse particles.

The importance of grading sand is to have the small size particles fill the spaces between the larger particles. The ideal aim in making concrete and mortar is to produce a substance as near as possible approximately the

density and strength of stone.

The results of grading sand according to Fuller's ideal curve are:

(1) An average increase of strength of 14% over the ungraded sand.

(2) The ideal curve for concrete does apply to mortar.

The ideal mixture had too much of the coarse particles, as most of the particles smaller than the #10 sieve had to be discarded. It is believed by making further investigations on the same line, that a mixture can be obtained that will apply to mortar. By proper grading, a leaner mixture, thus saving in the cost of cement.

Bibliography.

Masonry Construction Baker

Concrete Plain and Reinforced, Taylor and Thompson

Portland Cement Mortars and their Constituent Materials, U. S. Geological Survey Bulletin #329.

Mortar Making Qualities of Illinois Sands, University of Illinois Experiment Station, Bull. #70.

Tests of Mortars made from Wisconsin Aggregate, Proceedings of the American Society for Testing Materials Vol. 13 page 834. M. O. Withey.

The Economic Side of Sand Testing, Engineering Record, Vol. 71 page 551 Chapman and Johnson

Safe Concrete Demands Knowledge of Nature of Sand Engineering Record Vol. 71 page 771, Chapman and Johnson.

Quality of Concrete Controlled by Tests of Sand Engineering Record Vol. 71 page 801 Chapman and Johnson.

Structural-Materials Testing Laboratories at St. Louis, Mo., U.S. Geological Survey Bulletin #329.